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Crop Classification Possibilities with Radar in ERS-1 and JERS-1 Configuration

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Classification possibilities of agricultural crops were studied using multitemporal, airborne radar data in ERS-1 and JERS-1 SAR configuration. The radar data were collected with the DUTSCAT scatterometer during the Agriscatt campaign over an agricultural test site in The Netherlands in 1988. In both ERS-1 and JERS-1 configuration, winter wheat, potato, sugar beet, and grass were differentiated in combinations of early-middle and early-late season observations. The distance between the centers of the clusters of these crops (in the early-middle and the early-late season combinations) varied between 1.6 dB and 9.3 dB in the ERS-1 and between 3.1 dB and 9.7 dB in the JERS-1 configuration. The average standard deviation of the crop-type clusters was 0.7 dB in the ERS-1 and 1.2 dB in the JERS-1 configuration. In the ERS-1 configuration, pea, stem bean, and onion were likely to be confused with sugar beet and grass, but more fields were needed to derive firm conclusions. In the JERS-1 configuration, stem bean and onion were well discriminated, and rapeseed and pea were confused with winter wheat and beet. The combination of data in the ERS-1 and the JERS-1 configuration increased the classification possibilities for all crops.

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INTRODUCTION

On 17 July 1991, the European radar remote sensing satellite ERS-1 was successfully launched and put in orbit. The payload consists of, among other instruments, a Synthetic Aperture Radar (SAR) that operates in the C-band (5.3 GHz), at VV polarization and with a central nadir look angle of 23°. In 1992, the Japanese remote sensing satellite JERS-1 is scheduled for launch. This satellite will carry among other instruments, an L-band (1.28 GHz) SAR, operating at HH polarization and with a central nadir look angle of 35°. Both spaceborne SARs will provide regular imagery of the Earth's surface, unhindered by clouds or atmospheric conditions. An important identified land application of both SARs is crop type classification and acreage inventory. This type of information is useful for agricultural statistics, in both the industrialized Western world and the less-developed Third World.

To prepare the advent of spaceborne SARs, the European Space Agency and the Joint Research Centre of the European Community initiated the airborne radar campaign Agriscatt 1987–1988 (Attema, 1989; Hoekman, 1990). In this campaign, multitemporal, multifrequency, and multipolarization radar data were gathered with, among other instruments, the DUTSCAT [Delft University of Technology SCATterometer (Snoeij and Swart, 1987)] over selected agricultural test sites in Europe. The Centre for Agrobiological Research (CABO) participated in this campaign with a test site in Southern Flevoland in The Netherlands. In this paper, the DUTSCAT data over the Flevoland test site in 1988 were used for a feasibility study of crop type classification using data in ERS-1 and JERS-1 configuration (i.e., frequency, incidence angle, and polarization). Because the radar data were collected with a scatterometer, and not with an imaging SAR system, the analysis was restricted to the interpretation of field-average radar backscattering. Crop type classification possibilities were considered in the ERS-1 and the JERS-1 configuration separately, and in combined use (possibly in 1992).

MATERIALS

The Flevoland Test Site

The Dutch test site was located in Southern Flevoland, a polder reclaimed from Lake Ijssel in 1966. The land surface of this polder is flat and the soils are homogeneous over large areas. Within the test site, the soil is classified as a fine textured Calcaric Fluvisol (World Soil Map FAO). The clay content in the top soil varies between 30% and 35%, the organic matter content between 4% and 6%, and carbonates are often present in the form of shell remnants. The mean altitude is 3 m below sea level. Southern Flevoland is mainly an agricultural area with the principal crop types wheat, potato, and sugar beet (about 30% of the total acreage each). Secondary crops include grass, maize, barley, pea, onion, stem bean, and rapeseed.

The test site in Southern Flevoland was comprised of seven rectangular shaped agricultural parcels of about 80 ha (Fig. 1). These parcels were subdivided into smaller fields by the farmers to grow several crop types and varieties. During the DUTSCAT overpasses, we collected qualitative and quantitative ground truth on fields of winter wheat, potato, and sugar beet (three fields each), and spring barley and stem bean (one field each). Table 1a lists the fraction soil cover, the dry canopy biomass, the leaf area index (LAI), and, for cereals, the Zadoks decimal growth stage, as averages per crop type. The fraction soil cover was visually estimated by an expert in the field with an accuracy of about 0.01 at early growth to 0.05 at full crop cover. The canopy biomass was measured from five samples of 1 m^2 per field, and the LAI from a subsample of these five square meter samples per field. The standard deviations of the average values for winter wheat, sugar beet and potato are also given in Table 1a. The crop type varieties were Obelisk for winter wheat; Bintje for potato; Regina, Accord, and Univers for

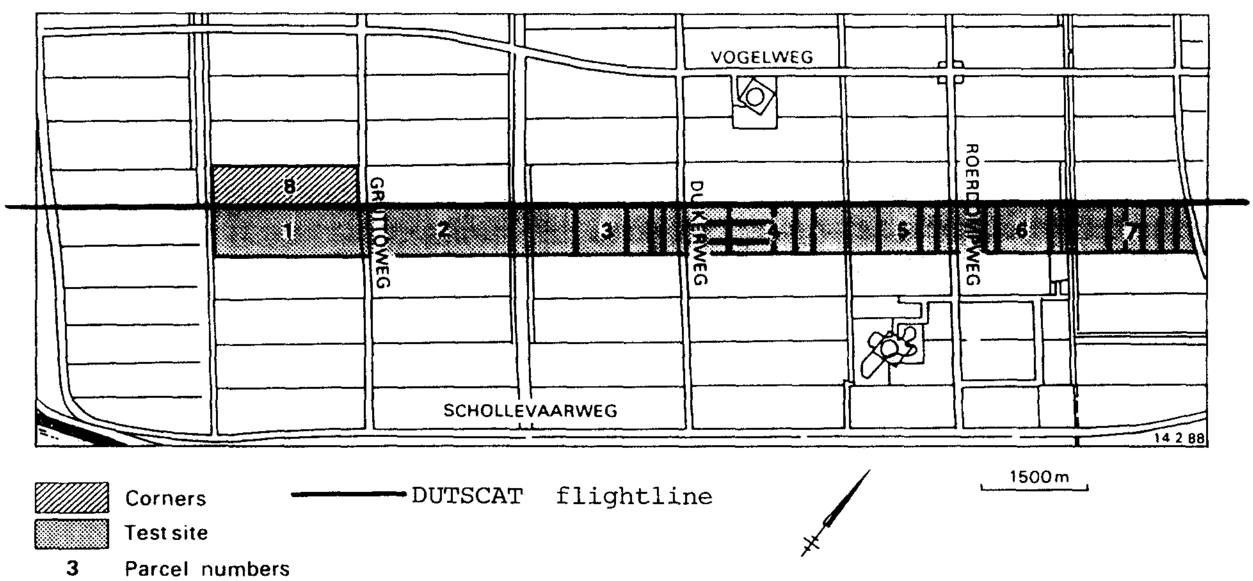

Figure 1. The seven agricultural test parcels in Southern Flevoland, divided into test fields with different crops and varieties.

Table 1a. Crop Growth Parameters and Standard Deviations for Winter Wheat, Potato, Sugar Beet (Average of Three Fields Each) and Spring Barley and Stem Bean (One Field), at Radar Observation Days[a]

Day	*C*	*L*	*B*	*Z*	*C*	*L*	*B*	*C*	*L*	*B*
	Winter Wheat				*Potato*			*Sugar Beet*		
112	0.4	1.3	1.0	13	0	0	0	0	0	0
122	0.55	2.7	2.0	24	0	0	0	0	0	0
165	0.95	4.1	10.5	52	0.45	1.0	0.7	0.38	0.7	0.8
186	0.9	3.7	14.5	77	0.9	2.5	1.5	0.78	3.0	2.2
195	0.9	2.0	14.5	79	0.95	3.3	2.2	0.82	3.3	3.5
207	0.6	1.0	15.5	79	0.9	3.6	2.7	0.82	4.2	4.5
228	—	—	—	—	0.97	4.4	3.4	0.95	5.0	6.0
	Spring Barley				*Stem Bean*					
112	0	0	0	—	0	0	0			
122	0	0	0	—	0	0	0			
165	0.93	4.5	2.6	31	0.35	1.5	1.2			
186	0.96	5.4	6.8	52	0.88	3.1	2.6			
195	0.95	3.7	7.6	65	0.90	5.4	6.3			
207	0.70	4.2	10.7	76	0.40	1.6	6.0			
228	0.80	—	10.6	90	0.30	1.2	7.2			

Standard Deviations

	Winter Wheat				*Potato*			*Sugar Beet*		
Day	*C*	*L*	*B*	*Z*	*C*	*L*	*B*	*C*	*L*	*B*
112	0.13	0.5	0.3	1	0	0	0	0	0	0
122	0.09	0.5	0.4	5	0	0	0	0	0	0
165	0.01	0.3	0.4	0	0.05	0.4	0.2	0.16	0.2	0.2
186	0.03	0.6	1.5	0	0.02	0.3	0.2	0.09	0.2	0.5
195	0.02	0.8	1.2	1	0.02	0.3	0.2	0.08	0.7	0.5
207	0.26	0.5	0.9	2	0.04	0.3	0.1	0.04	0.1	0.3
228	—	—	—	—	0.02	0.3	0.3	0.01	0.4	0.7

[a] C = fraction soil cover; L = leaf area index; B = dry canopy biomass in ton/ha; Z = Zadoks decimal growth stage for cereals (Zadoks et al., 1974).

sugar beet; Femina for spring barley; and Alfred for stem bean.

Only visual observations were made of one field of rapeseed, and two fields of pea (Table 1b). No ground truth was collected for maize, onion, and grass. Moreover, because the number of radar observation on maize was too low for analysis, this crop was discarded for this study.

DUTSCAT Radar Data

The airborne scatterometer DUTSCAT was operated in six frequency bands between the L- (1.2 GHz) and the Ku-band (17.3 GHz). The radar backscattering was measured seven times in the growing season at vertical (VV) and horizontal (HH) copolarization: days 112 (22 April), 122 (2 May), 165 (14 June), 186 (5 July), 195 (14 July), 207 (26 July), and 228 (16 August). The incidence angles varied between 20° and 60° in steps of 10°. The altitude of flight ranged from 100 m at 60° incidence angle, to 350 m at 20° incidence angle.

On days 112 and 122, the DUTSCAT data were compressed during recording due to wrong attenuator settings. These data were decompressed through an especially designed decompression algorithm (Snoeij et al., 1989). At each angle of incidence, state of polarization and frequency, DUTSCAT was externally calibrated on corner reflectors for each sortie by the Technical University of Delft. The Physics and Electronics Laboratory TNO and the CABO computed the average radar backscattering in γ for all agricultural fields in the seven test parcels (Luik, 1990). The relationship between γ (radar cross section of target per unit projected area) and σ° (radar cross section of target per unit illuminated area) is

$$\gamma = \sigma^{\circ} / \cos\theta,$$

where θ is the angle of incidence of the radar beam.

Table 1b. Visual Description of Crop Status of Pea, Rape Seed, and Bean during Radar Observation Days[a]

Day	*Pea (Two Fields)*
112	340: bare soil; rough; slaked; winter furrow; dry 740: bare soil; harrowed and sown; dry
122	340: bare soil; rolled and smooth surface; dry 740: bare soil; dry
165	340: healthy crop with twines, some flower buds; dry 740: healthy crop with twines; dry
186	340: healthy crop, flowering; wet 740: healthy crop, flowering; wet
195	340: partly lodged; flowering; full with pods; wet 740: ≈ 75% lodged; flowering; full with pods; wet
207	340: harvested; straw on field; moist 740: harvested; ploughed; irregular surface; clods
228	340: bare soil; harrowed; dry 740: bare soil; ploughed
	Rape Seed (One Field)
112	Erect crop with flower buds; dry
122	Healthy crop, fully flowering; dry
165	Yellow/brown crop; green pods in upper canopy; dry
186	Crop without leaves; green/purple pods; wet
195	Harvested crop, collected on ridges (≈ 50 cm high); pods black; stubble green, erect (≈ 25 cm high); wet
207	Same as day 195; wet
228	Crop threshed with straw dispersed on field; stubbles erect, dried-out; shoots of weed and rape seed; dry
	Stem Bean (One Field)
112	Bare rolled soil; crop sown; dry
122	Bare soil; fine clods (≈ 2 cm); crop emergence; dry
165	Healthy crop; first flowers; dry
186	Healthy crop; fully flowering; wet
195	Closed canopy; flowers in upper part, pods in lower; wet
207	Diseased crop (brown leaf speckles); ≈ 30% of crop leafless; lower part in canopy without leaves; green pods; moist
228	As 207; dry

[a] The terms "wet," "moist," and "dry" refer to the state of the crop canopy or that of the soil surface.

In a comparative analysis at the CABO with other radar systems in the C- and/or X-band (especially the French ERASME scatterometer that operated simultaneously with DUTSCAT on days 165–207), the DUTSCAT data were found to be 3–8 dB higher on an absolute scale (Bouman et al., 1990). The relative trends, for example, differences between crop types, were comparable.

Details on the DUTSCAT, data processing, data calibration, and quality analysis are given by Snoeij et al. (1987; 1989) and Bouman et al. (1990). In the whole chain of radar data processing from raw data to quality-checked field-average γ values, the close cooperation between agriculturalists, physicists, and technicians was a crucial factor.

For this study, the DUTSCAT radar data in the C-band (5.3 GHz) at VV polarization and 20° and 30° incidence angle, and in the L-band (1.2 GHz) at HH polarization and 30° and 40° incidence angle were selected to mimic the ERS-1 and JERS-1 SAR configuration, respectively.

The data in the L-band were supposed to have a relative accuracy between observation days of 1–2 dB (possibly larger between days 112–122 and days 165–228 because of the original decompression of the data on the first two dates (Snoeij, personal communication)].

The temporal curves of γ in the C-band showed large peaks and dips, and the calibration between observation days was considered unreliable. Therefore, the C-band radar data were standardized in time by comparison with the L-band. The C-band data were linearly transformed so that the shape of the temporal curve of onion in the C-band matched that of the temporal curve in the L-band. This way, smooth temporal signatures were obtained that allowed the comparison of the *relative* behaviour of the temporal curves of

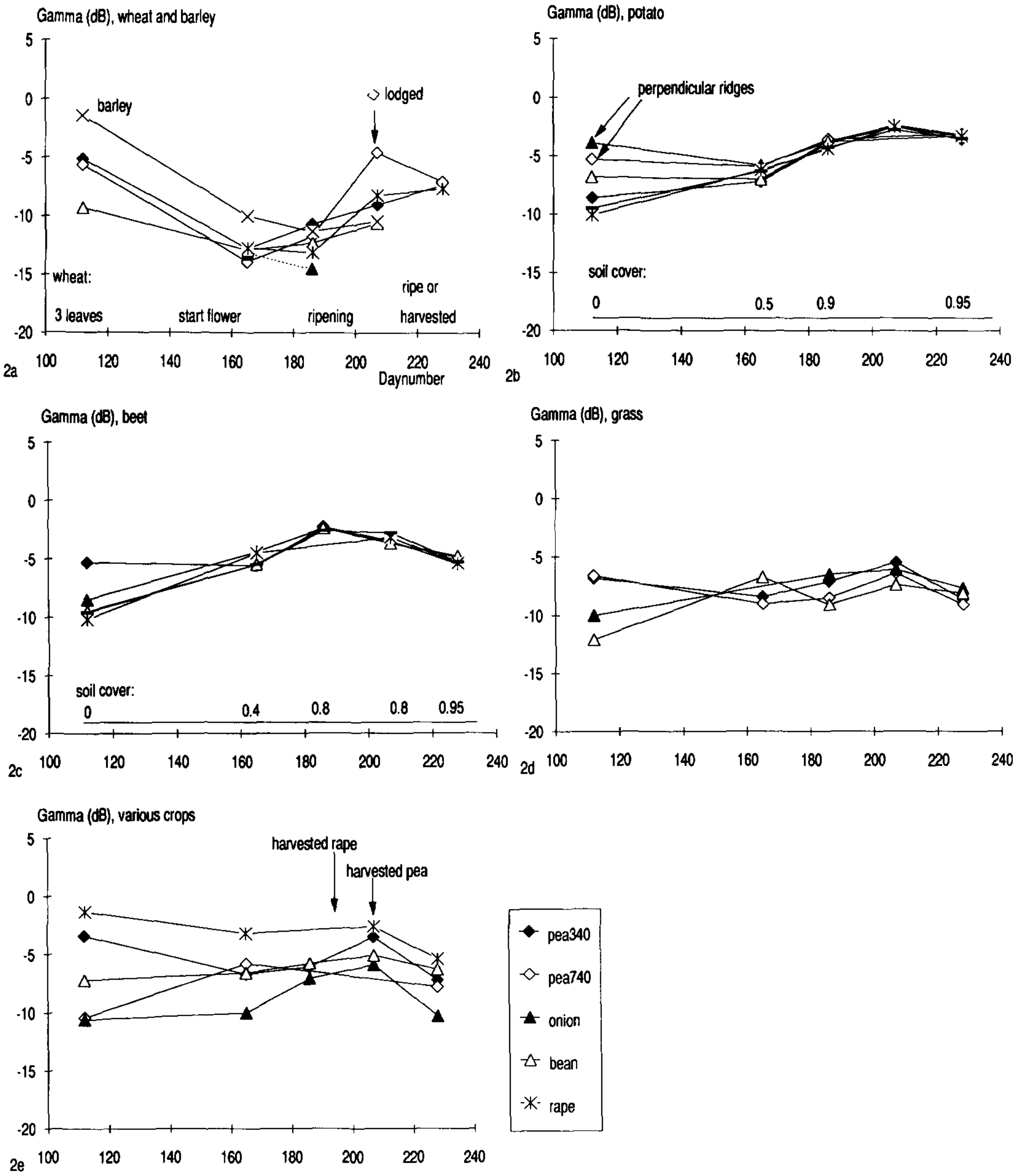

Figure 2. Temporal radar backscattering γ of winter wheat and spring barley (2a), potato (2b), sugar beet (2c), grass (2d), and of pea, onion, stem bean and rapeseed (2e), in ERS-1 configuration: C-band, VV, 20° incidence angle.

different crop types in both bands. Onion was chosen for standardization because of an expected resemblance to bare soil in both bands (onion has a very thin canopy with a low amount of canopy water). In the C-band, because of the low incidence angle at 20° and 30° (de Loor, 1987), and in the L-band because of the relative magnitude of the wavelength, that is, ≈25 cm.

TEMPORAL SIGNATURE ANALYSIS

Crop types may be discriminated on the basis of differences in backscattering characteristics and/or on the basis of the cropping pattern. For instance, the difference in sowing (early growth) between winter crops and spring crops may be used as a first discriminator between these crop

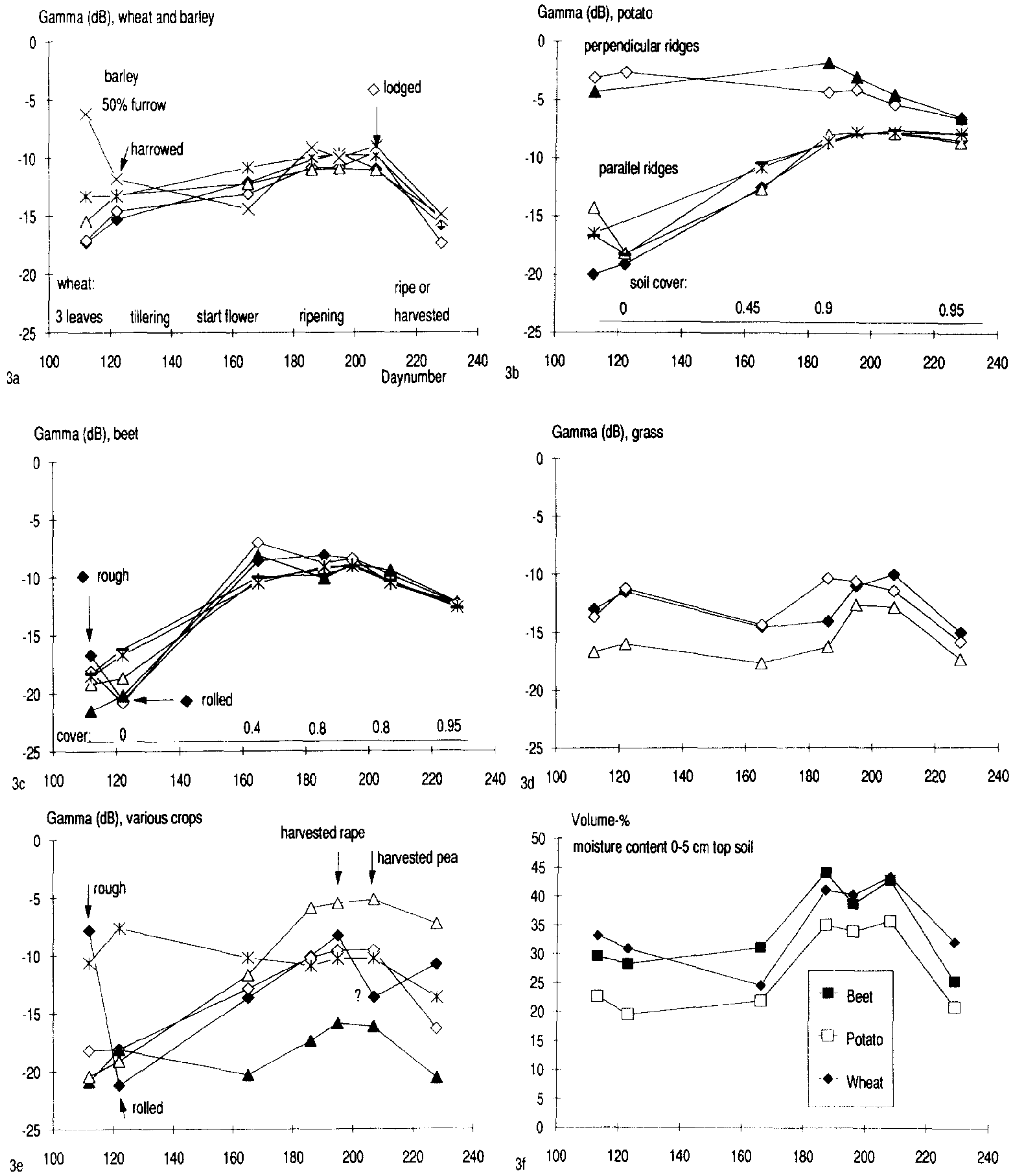

Figure 3. Temporal radar backscattering γ of winter wheat and spring barley (3a), potato (3b), sugar beet (3c), grass (3d), and of pea, onion, stem bean and rapeseed (3e), in JERS-1 configuration: L-band, HH, 40° incidence angle. The symbols used for the various crops in (3e) are the same as in Figure 2e. The average temporal course of the 0–5 cm top soil moisture content is given in 3f for sugar beet, potato, and winter wheat.

types in early spring (Hoogeboom, 1986; Uenk et al., 1987). Also, the radar backscattering of crops changes during the growing season in relation to growth and development. Characteristic backscattering features that are related to specific development stages of certain crops may be used as discriminators at specific moments in the growing season. Another important factor in discrimination possibilities is the variation between fields of the same crop type at different stages in the growing season. Therefore, the study of crop type discrimination possibilities was preceded by an analysis of the temporal curves of the radar backscattering in relation to the growth and development of the crops.

The temporal radar backscattering of the crop types in the test site is given in Figure 2 for the ERS-1 configuration (20° incidence angle) and in Figure 3 for the JERS-1 configuration (40° incidence angle). The growth and development of the crops can be read from Table 1. For comparison, the average temporal course of the top soil moisture content for some crops is given in Figure 3f.

It should be remembered that the temporal signatures in the L-band data may be "absolutely" interpreted, and the data in the C-band only "relatively" (between crop types)!

ERS-1 Configuration

Crop Type Clustering

Except for the first two dates of observation, the fields of the various crop types were well clustered together. The backscattering of bare soil on day 112 (and on day 122 and 30° incidence angle) varied due to variations in the surface roughness that were caused by tillage activities like ploughing, harrowing, sowing etc (see also the subsection on JERS-1 configuration).

The fields of potato (parallel ridges) and sugar beet were tightly clustered together within 1–2 dB. For *potato*, the effect of ridge orientation was notable with bare soil (ridges molded up) and in the early growing season (days 112–165). With a ridge direction perpendicular to the incident radar beam, the radar backscattering was larger than with parallel ridge direction. Though at 20° incidence angle, the ridge effect was no longer present on day 165 (Figure 2b), the radar backscattering from perpendicular fields was still 3 dB larger on that day at 30° incidence angle, and at 20° and 30° at HH polarization. The effect of ridge orientation only disappeared completely with about closed soil cover on day 186 (Table 1).

The clusters of *winter wheat* were somewhat broader, 2–5 dB, which may have been caused by the crops' sensitivity to canopy architecture at this wavelength [Bouman and van Kasteren (1990) have reported a relatively large sensitivity of X-band radar backscattering of wheat to variety, row spacing, and lodging]. Notice for instance the effect of 50% lodging of a single winter wheat field on day 207 (Figure 2a). The lack in contrast at the end of the growing season (day 228) between mature crops and stubble fields after harvesting was remarkable.

The clusters of *grass* were also relatively broad, 3–4 dB. This may have been caused by differences in mowing regimes of the various fields (no ground truth available). Bouman and Uenk (1987) have reported a relatively low backscattering for long grass with a high amount of canopy water, and a relatively low backscattering for short, mown grass with a low amount of canopy water in C-band SAR images collected with the Canadian IRIS over the same test site in 1987.

Signature Comparison

During the growing season, the relative radar backscattering of winter wheat and spring barley went down (until day 186), that of potato and sugar beet went up, and that of grass was more or less stable. From this, the discrimination between potato and sugar beet will be best in the late growing season (day 228), when the backscattering of potato remains constant and that of sugar beet goes down again. Rapeseed had the highest radar backscattering of all crops in the early growing season till day 195 (harvesting). Pea and stem bean had comparable signatures and may be confounded with sugar beet and potato in the early growing season (day 165), and with grass during the whole growing season. On day 186, pea and stem bean were well distinguished from potato and sugar beet. The absence of a marked (relative) reaction of the harvesting of rapeseed and pea on days 195 and 207, respectively, was remarkable.

The number of fields of winter wheat, potato, sugar beet, and grass was sufficiently large to substantiate the presented signatures and descriptions. For spring barley, pea, onion, stem bean, and rapeseed, the number of fields was only one (or two) per crop type. However, the independent observations at 30°, and at both 20° and 30° at HH polarization, confirmed above descriptions (also for the observations in the JERS-1 configuration).

Also, the relative behavior of these DUTSCAT C-band radar data agreed well with C-band radar data that were collected simultaneously with the ERASME (days 165–207, 20° and 30° incidence angle, HH polarization).

JERS-1 Configuration

Crop Type Clustering

As in the ERS-1 configuration, the backscattering of bare soils (days 112 and 122) was related to tillage activities. Notice, for instance, the relationship between γ and surface roughness for pea fields 340 and 740 (Table 1b). Similar relationships could explain differences in γ between other bare soil fields (Figs. 3a and 3c).

Except for winter wheat, the clusters of the crop types were broader than in the ERS-1 configuration. In *potato*, the effect of ridge orientation was much more dramatic and lasted throughout the growing season. The L-band microwaves still penetrated the potato canopy with full cover and a high amount of canopy water (≈ 2 kg/m^2 on day 195, ≈ 3 kg/m^2 on day 228).

For *winter wheat*, the crop clusters were narrower (only ≈ 2–3 dB) than in the ERS-1 configuration. The 50% lodging of a specific field on day 207 only increased the radar backscattering by ≈ 1 dB, versus ≈ 5 dB in the ERS-1 configuration. It is suggested that L-band microwaves were less sensitive to canopy structure of winter wheat than C-band microwaves. As in the ERS-1 configuration, there was no difference between mature crop and stubble fields after harvesting at the end of the growing season (day 228).

Signature Comparison

The temporal signatures of potato and sugar beet were comparable in trend in both the JERS-1 and the ERS-1 configuration: increasing backscattering with crop growth. Contrary to the ERS-1 configuration, the curves of winter wheat showed a slightly increasing backscattering with crop growth. After emergence, the temporal curve of spring barley joined that of the winter wheats. The temporal curves of grass were also different in the JERS-1 configuration, with a higher similarity between the fields. The temporal signatures of grass correlated somewhat with the temporal curves of top soil moisture content (Fig. 3f), and with the observed "wetness" of the canopies (Table 1b).

The variation between the temporal curves of the other crop types was larger in the JERS-1 than in the ERS-1 configuration. Rapeseed had typically the largest backscattering (except perpendicular potato) between the start and the early growing season, days 112–165, and a medium backscattering in the middle and late growing season, days 186–228 (even after harvesting, with the gathering of the straw on ridges). Stem bean had a low backscattering at the start of the season, and the highest backscattering (except perpendicular potato) in the middle and late season, days 186–228. Onion had typically the lowest backscattering of all from early to late growing season, days 165–228. The resemblance of the curve for onion with those of the top soil moisture content supported the hypothesis that the canopy of onion was relatively transparent to L-band microwaves (see the previous section).

Like in the ERS-1 configuration, the lack of a marked reaction in the radar backscattering on the harvesting of rapeseed and pea was remarkable [the "dip" (? in Fig. 3e) of pea field 340 on day 207 was not present at 30° incidence angle].

MULTITEMPORAL CLASSIFICATION

Based on the temporal signatures, it was suggested that observations in the early growing season (day 165), combined with observations in the middle (days 186–207) or the late (day 228) growing season would be most suitable for crop classification. At the start of the growing season, there was too much variation in the radar backscattering of bare soil to be useful for discrimination of winter crops. In both the ERS-1 and the JERS-1 configuration, the backscattering of rough, bare surfaces was often as high as that of winter wheat. Only after smoothing of the surfaces for sowing (e.g., day 122 in Fig. 3) could winter wheat be differentiated from bare soils in the JERS-1 configuration. In practice, winter wheat may then still be confused with grass, and with bare potato fields with ridge orientations that are between parallel and perpendicular to the radar beam.

The combinations of early–middle and early–late season observations are visually presented in feature-space plots in Figures 4 and 5. Some general statistics are given in Table 2. The terms early, middle and late growing season are related to the stages of crop growth given in Table 1.

ERS-1 Configuration

In the combinations of early–middle and early–late season observations, the main crop types winter wheat, potato, sugar beet, and grass were well discriminated (Fig. 4). The distance between the centers of the crop type clusters generally varied between 4 dB and 9 dB, with a mean standard

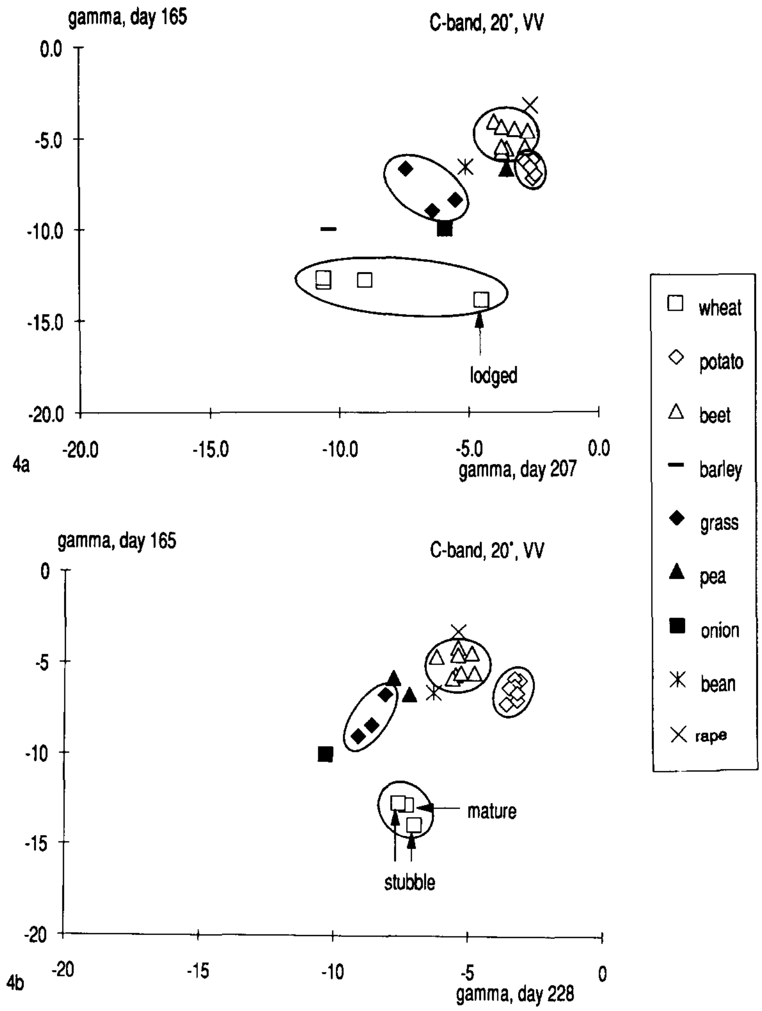

Figure 4. Feature space plot of radar backscattering γ in ERS-1 configuration on day 165 versus day 207 (4a) and versus day 228 (4b).

deviation of the crop type clusters of 0.4–1 dB (Table 2). Only the distinction between potato and sugar beet may be troublesome in the early–middle season combination, but becomes well feasible with a late season observation.

In practice, the cluster of potato may be broader in the early growing season because of random orientations of the ridge directions. In the middle and late season, however, the influence of ridge orientation will disappear. The cluster of winter wheat may be relatively broad in the middle and late growing season, especially when canopies start to lodge (note the relatively high value for the standard deviation of the cluster of winter wheat in the day 165–207 combination in Table 2).

The backscattering data of the other crops spring barley, pea, stem bean, onion, and rapeseed were spaced close to the clusters of the main crop types. More fields were needed to draw conclusions on the classification possibilities of these crops.

JERS-1 Configuration

In the JERS-1 configuration, the clusters of crop types were broader and generally spaced further apart than in the ERS-1 configuration (Fig. 5, Table 2). Especially the early–late season combination offered good possibilities for discrimination of the main crop types and grass. In practice, the clusters of potato may be diagonally elongated from the parallel to the perpendicular fields because of the (permanent) effect of ridge orientation. The clusters of winter wheat will be narrower than in the ERS-1 configuration, and less affected by lodging.

Stem bean was well identified in the early–middle season combination, and onion in both early–middle and early–late season combinations.

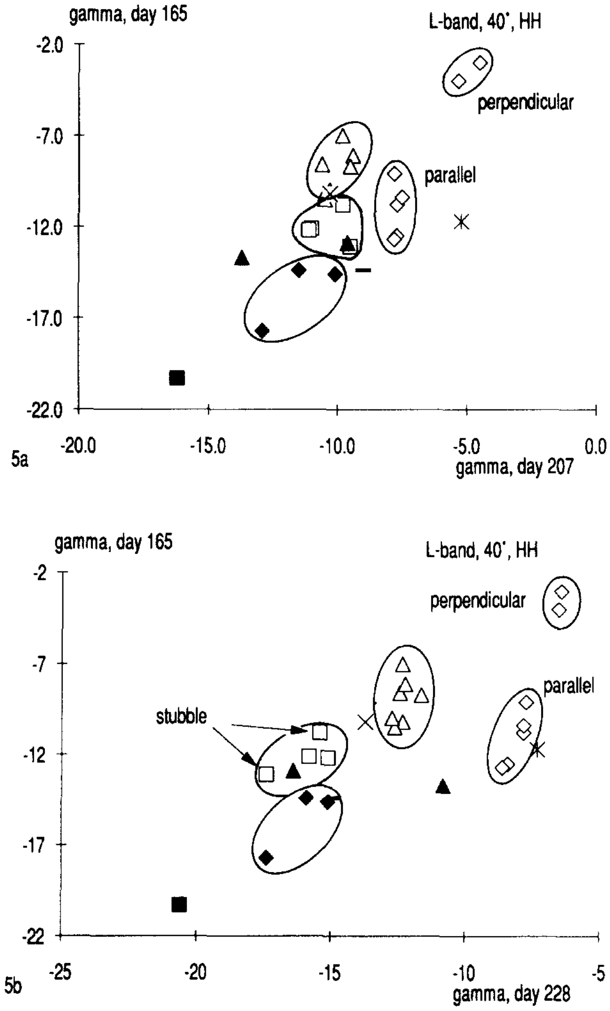

Figure 5. Feature space plot of radar backscattering γ in JERS-1 configuration on day 165 versus day 207 (5a) and versus day 228 (5b). The symbols used for the different crops are the same as in Figure 4.

Rapeseed and pea were confused with winter wheat and sugar beet. Again, more fields were needed to derive firm conclusions.

Combined ERS-1 and JERS-1 Data

Combined observations in both the ERS-1 and the JERS-1 configuration increased the possibilities for crop classification (Fig. 6, Table 3). Crop types that had relatively broad clusters in one configuration, for example, potato in JERS-1 (ridge orientation) and winter wheat in ERS-1 (lodging), had narrow clusters in the other.

Already in the early growing season, the main crop types were differentiated, though the discrimination between potato and sugar beet was troublesome. The distance between the clusters of potato and beet was only 2.4 dB, whereas the mean standard deviation of both clusters was 1 dB (Table 3). Near the late growing season, potato and sugar beet became very well differentiated, but here winter wheat and grass became confused.

The stable relative position of onion, and the characteristic changing position of stem bean indi-

Table 2. Distance between Centers, and Mean Standard Deviation of Crop-Type Clusters in Temporal Combinations of Observation Days 165–207 and 165–228, in ERS-1 and JERS-1 Configuration (See Also Fig. 4 and 5)

Distance between Centers of Crop-Type Clusters (dB)				
	ERS-1		*JERS-1*	
Observation Days	*165–207*	*165–228*	*165–207*	*165–228*
Wheat–potato	8.5	7.7	3.9	8.4
Wheat–beet	9.3	8.2	3.1	4.7
Wheat–grass	5.3	5.1	3.7	3.6
Potato–beet	1.6	2.5	3.7	5.1
Potato–grass	4.1	5.4	6.5	9.7
Beet–grass	4.2	4.2	6.8	7.6

Mean Standard Deviation of Crop-Type Clusters (dB)				
	Wheat	*Potato*	*Beet*	*Grass*
ERS-1				
165–207	1.6	0.4	0.6	1.0
165–228	0.4	0.4	0.6	0.9
JERS-1				
165–207	1.0	1.5	0.9	1.6
165–228	1.0	1.2	0.9	1.5

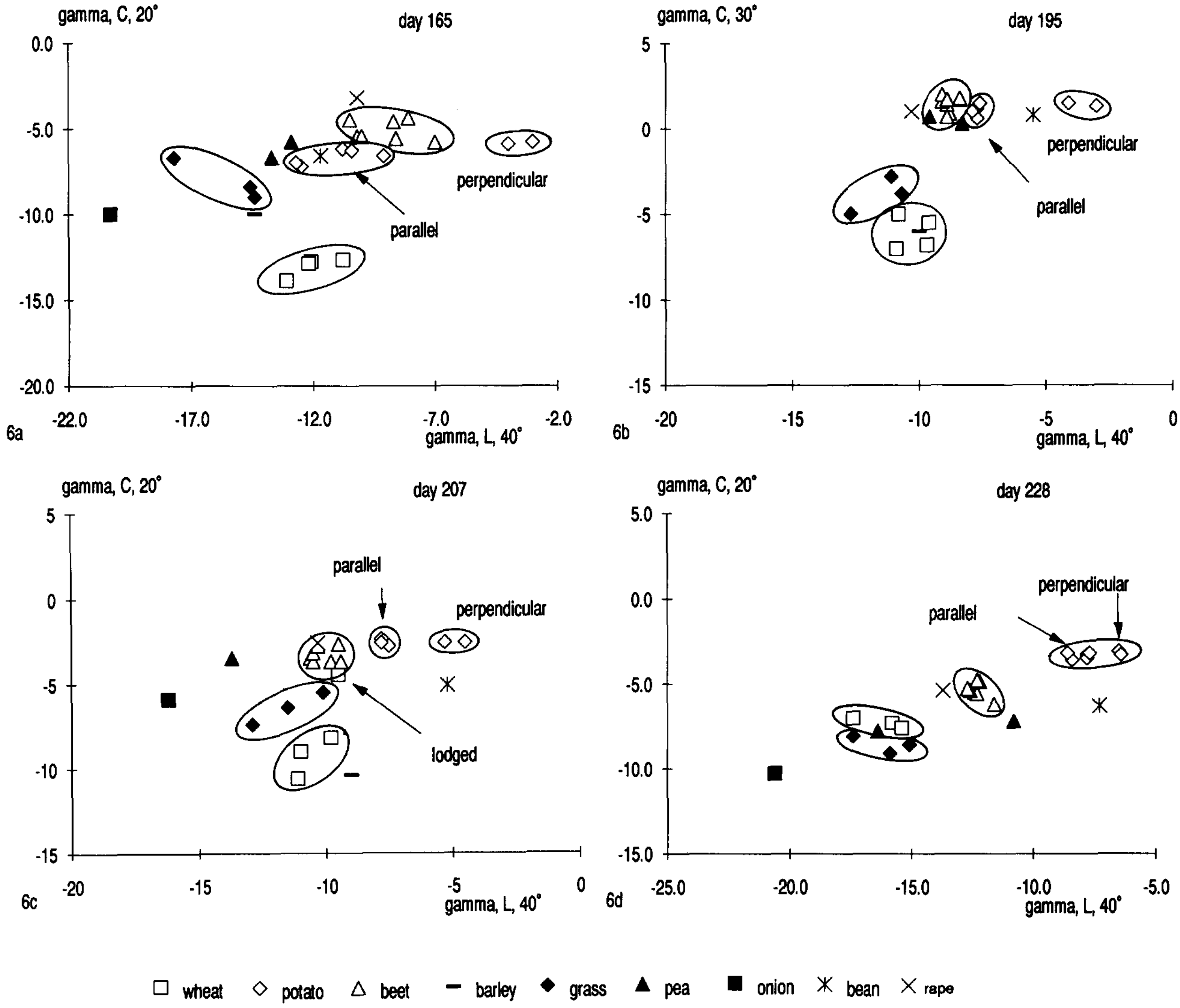

Figure 6. Feature space plot of radar backscattering γ in ERS-1 configuration versus JERS-1 configuration, on day 165 (6a), day 195 (6b), day 207 (6c), and day 228 (6d). Note that in (6b) the C-band data are given at 30° instead of at 20° incidence angle because of loss of data at 20° incidence angle.

Table 3. Distance between Centers, and Mean Standard Deviation of Crop-Type Clusters in Combinations of ERS-1 and JERS-1 Configuration, on days 165, 195, 207, and 228 (See Also Fig. 6)

Distance between Centers of Crop-Type Clusters (dB)				
Observation Day	*165*	*195*	*207*	*228*
Wheat–potato	6.7	9.4	6.6	9.2
Wheat–beet	8.5	10.1	4.7	4.0
Wheat–grass	6.2	5.6	1.9	1.1
Potato–beet	2.4	3.0	3.2	5.2
Potato–grass	4.9	8.0	6.0	9.9
Beet–grass	7.3	6.9	3.4	4.8
Mean Standard Deviation of Crop-Type Clusters (dB)				
	Wheat	*Potato*	*Beet*	*Grass*
165	0.8	1.0	1.0	1.5
195	1.0	1.6	0.6	2.1
207	1.8	0.8	0.5	1.1
228	0.7	0.6	0.4	0.9

cated good possibilities for multitemporal, dual-sensor classification.

CONCLUSION AND DISCUSSION

In both ERS-1 and JERS-1 configuration, the main crop types winter wheat, potato, sugar beet, and grass in the Flevoland test site were well differentiated in combinations of early–middle and early–late season observations. The early–late season combination offered better discrimination possibilities between potato and sugar beet than the early–middle season combination. The distance between the centers of the clusters of the main crop types (in the early–middle and early–late season combinations) varied between 1.6 dB and 9.3 dB in the ERS-1, and between 3.1 dB and 9.7 dB in the JERS-1 configuration. The average standard deviation of the main crop-type clusters was 0.7 dB in the ERS-1 and 1.2 dB in the JERS-1 configuration.

In the ERS-1 configuration, pea, stem bean, and onion were likely to be confused with other crops (namely, sugar beet and grass), but more fields were needed to derive firm conclusions. In the JERS-1 configuration, stem bean and onion were well discriminated, but rapeseed and pea were confused with winter wheat and beet. Compared to the ERS-1 configuration, the data in the JERS-1 configuration were spaced further apart, and had a higher dynamic range.

The combination of data in the ERS-1 and the JERS-1 configuration increased the classification possibilities for all crops. Already in the early growing season, the main crop types were discriminated, with possible confusion between potato and sugar beet. In many applications of crop type classification and acreage inventory, however, the early availability of estimates is of great importance, and the allowed accuracy may be lower than at the end of the growing season.

Possibilities for crop type classification are related to variety, growth, development stage, and general status of the crops involved. In the JERS-1 configuration, temporal variation in soil moisture conditions may influence classification results because of the penetration of L-band microwaves through crop canopies. Also, prevailing growing conditions and management practices of the farmers have to be taken into consideration. Insight into these (site-specific) factors, and into the effects on the radar backscattering are essential for successful crop identification (e.g., the effect of lodging or harvesting of wheat, mowing regime of grass, and ridge orientation in potato). Therefore, the results of the presented case study are only *indicative* for (good) crop classification possibilities with the ERS-1 and the JERS-1 in the Dutch Flevopolder or in comparable growth environments. Moreover, it should be noted that the number of fields was not sufficient for a statistically significant classification exercise.

Finally, from the spacing in and between the crop clusters, it is argued that, for successful crop classification with the ERS-1 or the JERS-1, the (relative) field-average radar backscattering γ should have an accuracy of preferably <1 dB.

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